

Cluster-based and cellular approach to fault detection and recovery in wireless sensor networks

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Abstract— In the past few years wireless sensor networks have received a greater interest in application such as disaster management, border protection, combat field reconnaissance, and security surveillance. Sensor nodes are expected to operate autonomously in unattended environments and potentially in large numbers. Failures are inevitable in wireless sensor networks due to inhospitable environment and unattended deployment. The data communication and various network operations cause energy depletion in sensor nodes and therefore, it is common for sensor nodes to exhaust its energy completely and stop operating. This may cause connectivity and data loss. Therefore, it is necessary that network failures are detected in advance and appropriate measures are taken to sustain network operation. In this paper we survey cellular architecture and cluster-based to sustain network operation in the event of failure cause of energy-drained nodes. The failure detection and recovery technique recovers the cluster structure in less than one-fourth of the time taken by the Gupta algorithm and is also proven to be 70% more energy-efficient than the same. The cluster-based failure detection and recovery scheme proves to be an efficient and quick solution to robust and scalable sensor network for long and sustained operation. In cellular architecture the network is partitioned into a virtual grid of cells to perform fault detection and recovery locally with minimum energy consumption. Fault detection and recovery in a distributed manner allows the failure report to be forwarded across cells. Also this algorithm has been compared with some existing related work and proven to be more energy efficient.

Keywords- Cluster head, Sensor Networks, clustering, fault detection, fault recovery & virtual grid

I. INTRODUCTION

Energy-constrained sensor networks require clustering algorithms for tackling scalability, energy efficiency and efficient resource management. Clustering prolongs the network lifetime by supporting localized decision-making and communication of locally aggregated data within the clusters thereby conserving energy [1]. The amount of energy consumed in a radio transmission is proportional to the square of the transmission range. Since the distance from sensor node to sensor node is shorter than sensor node to the base station, it is not energy efficient for all sensor nodes to send their data directly to a distant base station.

Therefore cluster-based data gathering mechanisms effectively save energy [1].

Sensor network faults cannot be approached similarly as in traditional wired or wireless networks due to the following reasons [2]:

1. Traditional wired network protocol are not concerned with the energy consumptions as they are constantly powered and wireless ad hoc network are also rechargeable regularly.

2. Traditional network protocols aim to achieve point-to-point reliability, where as wireless sensor networks are more concerned with reliable event detection.

3. Faults occur in wireless sensor networks more frequently than traditional networks, where client machine, servers and routers are assumed to operate normally. Therefore, it is important to identify failed nodes to guarantee network connectivity and avoid network partitioning. We aimed to maintain the cell structure in the event of failures caused by energy-drained nodes. In our scheme, the whole network is divided into a virtual grid where each cell consists of a group of nodes. A cell manager and a secondary manager are chosen in each cell to perform fault management tasks. A secondary manager is a back up cell manager, which will take control of the cell when cell manager fails to operate. These cells combine to form various groups and each group chooses one of their cell managers to be a group manager. The failure detection and recovery is performed after the formation of virtual grid. The energy drained nodes are detected and recovered in their respective cells without affecting overall structure of the network. We considered the case of node notifying their cell managers, when their residual energy is below the threshold value. The virtual grid based failure detection and recovery scheme is compared to Cluster-based failure detection and recovery scheme [3]. It can be result that failure detection and recovery in virtual grid based algorithm is more energy efficient and quicker than that of Cluster-based. In [3], it has been found that Cluster-based algorithm is more energy efficient in comparison with crash fault detection [4] and fault tolerant clustering approach proposed by Gupta and Younis [5]. Therefore, we conclude that our proposed algorithm is also more efficient than

Gupta and Crash fault detection algorithm in term of fault detection and recovery.

II. RELATED WORK

In this section, we review the related works in the area of fault detection and recovery in wireless sensor networks (WSNs). Many techniques have been proposed for fault detection, fault tolerance and repair in sensor networks [6–9]. A survey on fault detection in the context of fault management can be found in [10]. Fault tolerance in Internet such as network availability and performance has been discussed in [7]. Hierarchical and cluster-based approaches for fault detection and repair have also been dealt by researchers in [5]. In [11], a failure-detection scheme that using management architecture for WSNs called MANNA is proposed and evaluated. However, this approach requires an external manager to perform the centralized diagnosis and the communication between nodes and the manager is too expensive for WSNs. Several localized threshold-based decision schemes were proposed by Krishnamachari and Iyengar [14] to detect both faulty sensors and event regions. Luo et al. [12] did not explicitly attempt to detect faulty sensors, instead the algorithms they proposed improve the event-detection accuracy in the presence of faulty sensors. There have been several research efforts on fault repair in sensor networks. However, most existing approaches require knowledge of accurate location information. Some algorithms employ mobile sensor nodes to replace the faulty sensors and rectify coverage and connectivity holes. However, movement of the sensor nodes is by itself energy consuming and also to move to an exact place to replace the faulty node and establish connectivity is also tedious and energy-consuming. Mei et al. [13] proposed a method to use mobile robots to assist sensor replacements for the failed sensor nodes. They study the algorithms for detecting, reporting sensor failures and coordinating the energy-efficient movement of the mobile robots. A replacement protocol for failures in hybrid sensor networks is proposed in [15]. In this paper, the mobile sensors are used to recover from faults or to improve the coverage and connectivity of the network. The faulty sensors locate redundant sensors and initiate request for replacement.

III. SURVEY VIRTUAL GRID BASED FAILURE DETECTION AND RECOVERY ALGORITHM

A. Cellular formation

The sensor network nodes configure themselves into a virtual grid structure, in which the network nodes are partitioned into several cells each with a radius that is tightly bounded with respect to a given value R . Detail of this cellular architecture has been revealed in [17]. A cell can be considered as a special kind of clustering. However it is more systematic and scalable. Cells can merge together to produce large cells that would be managed using the same

process. Division of network into virtual grid helps in achieving self configuration, in which it must actively measure network states in order to react to the network dynamics. A grid-based architecture is feasible in a network in which nodes are relatively regularly deployed. We assume that communicated data is fault free and that all semantic-related generic faults are detected and removed by the application itself. Furthermore, we assume that there will be no alterations or creations of messages over the transmission links. One node in each cell is distinguished as the cell manager, to represent this cell in the network. All cell managers in the network form an upper level grid and the remaining nodes form a lower level grid. Fig 1 depicts the organization of the nodes in a virtual grid. After the division of the network into small virtual cells as shown in Fig. 1, a cell manager is appointed in each cell. Initially, node with the highest co-ordinates in a cell becomes cell manager and node with the second highest co-ordinates becomes secondary cell manager.

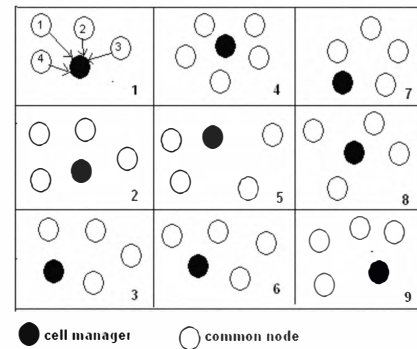


Fig. 1. virtual grid of nodes

Later on, selection of cell manager and secondary cell manager will be based on available residual energy. The node with the maximum residual energy will be chosen as cell manager or secondary manager. The cell manager receives data directly from its cell members and passes it to other neighboring cell managers. There is a one-hop communication between cell manager and its common members as shown in fig 1. After the selection of cell managers and secondary cell manager, cells combine to form various virtual groups. Each group of cells then selects a group manager with mutual co ordination. A group manager is a cell manager which performs its normal tasks for its own cell but at the same time act as a group manager for a group of cells. This is another level of virtual grid, on top of cell managers. The main goal of introducing group manager is to perform high level management tasks and predict future faults.

B. In cell failure detection and recovery

In this section, we discussed the mechanism to detect energy depletion failures in the network and how it is reported to

relevant nodes to initiate recovery. Identification of faulty nodes can be achieved by two mechanisms i.e. through regular energy messages to cell manager and nodes themselves notify the managing nodes of its residual energy (if its below the required threshold value). In regular energy messages to managing nodes, common nodes in each cell send their energy status as a part of update_msg to their cell manager. The update_msg consists of node ID, energy and location information. A faulty node will be identified, if the cell manager does not hear from it. In this paper, we focused on the first mechanism as fault identification through regular energy messages has been discussed in [19]. A node is termed as failing when its energy drops below the threshold value. When a common node is failing due to energy depletion, it sends a message to its cell manager that it is going to a low computational mode due to energy below the threshold value. Thus, no recovery steps are required in the failure of common node. Cell manager and secondary cell manager are known to their cell members. If cell manager energy drops below the threshold value, it then sends a message to its cell member including secondary cell manager. Which is an indication for secondary cell manager to stand up as a new cell manager and the existing cell manager becomes common node and goes to a low computational mode. Common nodes will automatically start treating the secondary cell manager as their new cell manager and the new cell manager upon receiving updates from its cell members; choose a new secondary cell manager. Recovery from cell manager failure involved in invoking a backup node to stand up as a new cell manager. The failure recovery mechanisms are performed locally by each cell. In Fig.1, let us assume that cell 1's cell manager is failing due to energy depletion and node 3 is chosen as secondary cell manager. Cell manager will send a message to node 1, 2, 3 and 4 and this will initiate the recovery mechanism by invoking node 3 to stand up as a new cell manager.

C. Overall cell failure detection and recovery

Each cell maintains its health status in terms of energy. It can be High, Medium or Low. These health statuses are then sent out to their associate group managers. Upon receiving these health statuses, group manager predict and avoid future faults. For example; if a cell has health status high than group manager always recommend that cell for any operation or routing but if the health status is medium than group manager will occasionally recommend it for any operation. Health status Low means that the cell has insufficient energy and should be avoiding for any operation. Therefore, a group manager can easily avoid using cells with low health status. Consider Fig.1, let cell 4 manager be a group manager and it receives health status updates from cell 1, 2 and 3. Cell 2 sends a health status low to its group manager, which alert group manager about the energy situation of cell 2.

IV. SURVEY CLUSTER-BASED FAILURE DETECTION AND RECOVERY ALGORITHM

The nodes are organized into clusters and network operates for some time. The data communication and network operation causes energy depletion in the sensor nodes. The schemes for failure detection and cluster recovery are activated in the event of failures due to energy-drained nodes. In this paper, the maintenance and recovery of the cluster structure in the event of node failures is termed as failure recovery. We now further elaborate on the failure detection and failure recovery mechanisms.

A. Failure detection

Every node has a record of its balance energy. The nodes in each cluster send their energy status as a part of the hello_msg, to their first hop members including their parent. The hello_msg consists of the location (x and y coordinates), energy and node ID. This hello_msg conveys the current energy status of the node. When the node is failing, it sends the failure report message fail_report_msg to its parent and children. A node is termed as failing when its energy level drops below the threshold value, E_{th} . The threshold value, E_{th} , is the energy required to transmit D number of l-bit messages across a distance equal to the transmission range.

In Fig. 2, let us assume that node 7 is failing, and then it sends a fail_report_msg to node 3, its parent and node 10 its child. Here we deal with failures related to energy

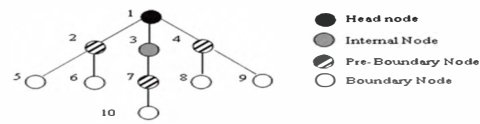


Figure 2. Cluster topology

exhaustion, and therefore we assume that the failing node can send the failure report to its immediate hop members before it dies completely. This information of the failure report is an indication to start the failure recovery process. The parent and children of the failing node are sufficient to invoke the failure-recovery mechanism. Therefore energy is saved by not allowing all the nodes in the cluster to detect a failure..

B. Failure recovery

The node failures discussed here is confined to failure due to energy exhaustion. The failure-recovery mechanisms are performed locally by each cluster. When a node fails, the failing node's parent and children take appropriate action to connect the cluster and bridge the gap formed by the failing node. We have proposed four types of failure mechanisms depending on the type of node in the cluster. The nodes in the cluster are classified into four types, boundary node, pre-boundary node, internal node and the head node. The descriptions of each node are explained in Table 1 and illustrated in Fig. 1. Fig. 1 gives an illustration of the

organization of the nodes in the clusters formed. The nodes in the clusters are organized in a tree-like manner with a parent and children. Let us consider the cluster to have a size of 10 and supportable degree (number of neighbours that each node can have as the next hop) as 3. Every node has a different mechanism for failure recovery. We now discuss the various failure recovery algorithms for a boundary node, pre-boundary node, internal node and a head node. We first explain the routines that are commonly implemented by the four types of nodes.

C. Common routines followed by recovery Algorithms

- **Failure reporting:**

A node is considered failing if its energy falls below the threshold energy. A failure report message, `fail_report_msg`, is sent by the failing node to its parent and children. This helps the children to realize that they need to search for another suitable parent for further operation. Once the parent receives the failure report, it ignores the failing node for further data transactions and considers it a non-active member.

Table 1. Different types of nodes

Type of node	Description	Figure description (Fig. 2)
Boundary node	a node which has no children	nodes 5, 6, 8, 9, 10
Pre-boundary node	a node whose children are all boundary nodes	nodes 2, 4, 7
Internal node	a node which has at least one pre-boundary or internal node as child.	Node 3
head node	Cluster head for the cluster	Node 1

- **Procedure for finding a suitable healthy parent:**

A `join_request_msg` is sent by the healthy child of the failing node to its neighbours. All the neighbours within the transmission range respond with a `join_reply_msg` / `join_reject_msg` message. The healthy child of the failing node then selects a suitable parent by checking whether the neighbour is not one among the children of the failing node and whether the neighbour is also not a failing node. If the healthy child is a boundary node, it first searches for a parent within a cluster, if not successful, it then searches for a parent outside the cluster. While searching for a parent, it checks whether the supportable degree of the neighbour is within the limit D , if the parent is of the same cluster. If the parent is from different cluster, the supportable degree of

the neighbour must be within the limit D and the cluster size limit also must be within S . If a healthy child is an internal node, it searches for a suitable parent inside the cluster only. If a suitable parent is found, then the healthy child node attaches itself to the chosen parent. The `cluster_info_msg` is exchanged if the chosen parent is from a different cluster. The cluster parameters of the child are updated to that of the new chosen parent through `update_msg` and data transmissions then follow the new paths. The failing node is then left with the original parent and its children are all allocated different parents to keep their data transmissions uninterrupted.

- **Head node failure-recovery algorithm**

. If the child of the failing cluster-head node is failing as well, then the treatment depends on the type of the node. The failing child is ignored completely if it is a boundary node. If the failing child is not a boundary node, then it will be ignored in this stage of head-node recovery. However, this node will be treated accordingly in one of the procedures for the failure recovery at a later stage as an internal or a pre-boundary node. Soon after the cluster head fails, another new cluster head is elected to manage the cluster.

- **Procedure for choosing another suitable**

Cluster head for the cluster: The children of the failing cluster-head node exchange their energy status. The children who are failing are not considered for the new cluster-head election, and they send `tentative_CH_msg`. The healthy child with the maximum residual energy is selected as the new cluster head and it sends a `final_CH_msg`. After the new cluster head is selected, the other children of the failing cluster head are attached to this new cluster head and the new cluster head becomes the parent for these children. The failing cluster head also makes the new cluster head as its parent. Since the supportable degree limits need to be maintained, the children of the new cluster head find a suitable parent inside the cluster. This re-allocation helps maintain the cluster size limits and also the supportable degree limits.

V. CONCLUSION

In this paper we survey a localized cellular based scheme and Cluster-based Scheme for fault detection and recovery in wireless sensor network of. Clustering has been used to address various issues i.e. routing, energy efficiency, management and huge-scale control. Therefore clustering can be formed in several ways. Nodes generally form a cluster in two stages: (1) a header is selected among the nodes through election algorithm, randomized election, degree of connectivity or pre-definition, and (2) the headers and the nodes interact to form a group or a cluster [33]. Cluster heads are responsible for coordinating the nodes in their clusters and generally are more resourceful than its cluster members. Cluster heads are the traffic bottlenecks; their failure may cause several problems. Also, if a cluster head failed to operate then no messages of its cluster will be

forwarded to the base station and selection of the new cluster head is energy consuming. Virtual Grid based architecture also divides the network into small virtual cells and each cell consists of a group of nodes, managed by a cell manager. In clustering, the most intuitive way to recover from a cluster head failure is to re-cluster the network. However, re-cluster is not only a resource burden on the sensor nodes but often very disruptive to the ongoing operation. Therefore, we introduced a backup node for recovery from cell manager failure. It does not affect network operation and consume no energy in order to recover from cell manager failure. Heterogeneous network comprises of nodes with different energy levels. Some nodes are less energy constrained than others. In such type of networks the less energy constrained nodes are chosen as cluster head of the cluster. Usually, these less energy constrained node are uniformly distributed with multi-hop communication. Nodes close to these cluster heads are under sever load as traffic routed from different areas of the network to the cluster head is via the neighbours of the cluster head. This results rapid dying of the nodes in the vicinity of the cluster heads, creating connectivity loss and in some cases network partitioning. Our approach addresses this challenge by employing a load balancing strategy so that all nodes operate together for as long as possible. We consider that all the nodes in the network are equal in resources and no node should be more resourceful than any other node. The optimal role assignment and reconfiguration scheme support the network management system to utilize the network nodes in the most efficient manner. Our approach does not rely on specific nodes with extra resources but assign tasks due to their optimal capabilities. Nodes are ranked according to their available energy. Therefore, the selection of cell manager and group manager is based on the available energy. The basis idea of this design is to encourage nodes to be more self manageable and extend the network life time for as long as possible. Also, distributed management system has lower communication costs and provides better reliability and energy efficiency. Virtual Grid based divides the whole network into a virtual grid and enables the network to perform local detection and distribute the management tasks across the network. This approach helps sensor nodes to take more management responsibility and decision-making in order to success the vision of self managed WSNs. Also, this increases network life time. The cellular architecture is for management purpose only so they can be merged into clusters for routing or any other purpose if needed. This scheme outperforms the Cluster-based algorithm with respect to fault detection and recovery in term of energy efficiency and time. The results obtained clearly that virtual grid based algorithm perform failure detection and recovery much faster than cluster-based algorithm and consumed significantly low energy.

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